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Measurement of Condensable Vapor Contribution to PM10 Emissions

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16. ABSTRACT The paper describes the woodstove dilution sampling system (WSDSS), the results of laboratory characterization of the device, and field measurements of residential woodstove emissions. During the past several years, SoRI has been involved with the development and testing of sampling trains for condensable emissions. Under EPA contract, SoRI designed and constructed a stack dilution sampling system (SDSS) for field measurement of condensable emissions. This train was used to measure condensable components of inhalable particulate matter at several sources. Also developed under EPA contract at SoRI was the ESDSS, a reduced-scale dilution sampling system, which is mechanically suitable for fireplace and wood heater emissions measurement. Certain smaller scale sources are rich in condensables. Residential woodstoves, for example, emit large quantities of condensable as well as volatile and semi-volatile organic species. The potential health impact of woodstove emissions may be expected to be influenced by these substances. Thus, in order to adequately assess the effect of woodstove particulate emissions on the near-source environment, measurement techniques must be used which do not discriminate against the condensable emissions. Ambient particulate samplers collect the woodstove particulate matter after the plume-mixing dilution and cooling process.

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Measurement	Sampling	Stationary Sources	14B	
Stoves	Particles	Woodstoves	13A	14G
Wood		Condensables	11L	
Fireplaces		Particulate		
Condensing			07D	

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MEASUREMENT OF CONDENSABLE VAPOR CONTRIBUTION TO PM10 EMISSIONS

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Introduction

In addition to gaseous and particulate pollutants, hot flue gases from some stationary emission sources contain significant amounts of vapor-phase substances which condense as the plumes cool. Such compounds have vapor pressures in the range so that their gas-phase concentrations are significant at stack temperatures, but when the emitted flue gases cool, these compounds are deposited on particulate phase material. In general, the new particulate masses formed by this condensation process can be expected to lie in the respirable and PM_{10} size ranges.

While condensable compounds are not generally the major contributor to particulate emissions, they occasionally can be important. For example, in sources which have high efficiency particulate controls, the condensable contribution may outweigh the nonvolatile particulate. Certain other smaller scale sources are rich in condensables. Residential wood stoves, for example, emit large quantities of condensable as well as volatile and semi-volatile organic species. The potential health impact of wood stove emissions may be expected to be influenced by these substances. Thus, in order to adequately assess the effect of wood stove particulate emissions on the near-source environment, measurement techniques must be used which do not discriminate against the condensable emissions. Ambient particulate samplers collect the wood stove particulate matter after the dilution and cooling process which occurs as the plume mixes with ambient air. The samples also contain an unknown, variable contribution of background particulate matter such as windblown dust, automobile exhaust, and particulate from other local sources. In measurements of wood stove particulate matter for source apportionment studies and for chemical and biological characterization, the sampler should duplicate as nearly as possible the plume mixing process without the addition of such background interferences.

During the past several years Southern Research Institute (SoRI) has been involved with the development and testing of sampling trains for condensable emissions. Under EPA contract, SoRI designed and constructed a Stack Dilution Sampling System (SDSS) for field measurement of condensable emissions. This train was used to measure condensable components of inhalable particulate matter at several sources, including a domestic oil-fired heater, an oil-fired utility boiler, a coal-fired power plant, a continuous drum mix asphalt plant, and, with slight modification, a fluidized bed hazardous waste incinerator. A reduced-scale dilution sampling system, the Wood Stove Dilution Sampling System (WSDSS), which is mechanically suitable for fireplace and wood heater emissions measurement, was developed under EPA contract at Southern Research Institute. This paper describes the WSDSS, results of laboratory characterization of the device, and field measurements of residential wood stove emissions.

Instrument Description and Operation

Design of WSDSS

A diagram of the major components of the Wood Stove Dilution Sampling System is shown in Figure 1. In operation, sample gas is extracted from the chimney flue through a sharp-edged nozzle, heated probe, and inlet section and introduced axially into the bottom of the cylindrical dilution chamber. At this point, the stack gas is mixed with dilution air to form a simulated plume which flows up through the dilution chamber. Particulate matter produced by direct combustion, along with any new particulate formed by condensation, is collected on a 142 mm filter at the top of the chamber. Organic substances which remain in vapor phase are adsorbed by an XAD-2 resin cartridge in series downstream from the collection filter. The diluted stream is then exhausted through the control module by a 10 cfm (283 lpm) pump. Sampled stack gas is measured by a venturi (2.71 mm throat dia.) at the base of the sample inlet. Dilution and exhaust flow are measured by orifices (9.53 mm dia.) at the inlet section and the control module, respectively.

As can be seen in Figure 2, the dilution air enters the sample inlet section perpendicular to the sample flow. The dilution air is then deflected toward the bottom of the inlet section to aid in providing an even flow distribution throughout the annulus. Before mixing with the sample gas the dilution air travels up through a region containing approximately 2250 flow straightening glass capillary tubes (1.8 mm O.D. x 1.5 mm I.D. x 100 mm long). The uniform annulus of dilution air ensures that mixing does not occur too quickly, simulating real-time ambient plume formation. As with the original SDSS, the ratio of the areas of the two inlets is such that, for sample gas at room temperature, the velocities of the sample and dilution streams are approximately equal. Sample gas at stack temperature will be injected at a higher velocity proportional to the thermal expansion of the heated gas stream. This was judged the best simulation of a buoyant plume injected into stagnant air.

The hot sample gas enters the heat-traced portion of the sample inlet through a heated sampling probe. As shown in Figure 2, the flow monitoring venturi and sample lines within the inlet section are maintained at or slightly above stack temperature by a thermostatically controlled heating tape. To prevent excessive heat transfer from the sample line to the cool surfaces of the dilution air passage, Teflon spacers are used to isolate the heated portion from the base of the inlet section, and "dead air" space is created around the sample tube at the core of the annulus with a tube sheath. A Viton gasket at the top of the core/sheath assembly seals the dead air space from the dilution chamber.

After the sample gas and dilution air have mixed within the dilution chamber, the mixture passes into the filter/sorbent housing (see Figure 3). Particulate matter is collected on a 142 mm filter. A spacing ring between the dilution chamber and the filter surface allows the gas mixture to expand beyond the inner diameter of the chamber, utilizing a maximum amount of available filter surface area. Organic substances which remain in the vapor phase pass through the filter and are absorbed by a sorbent

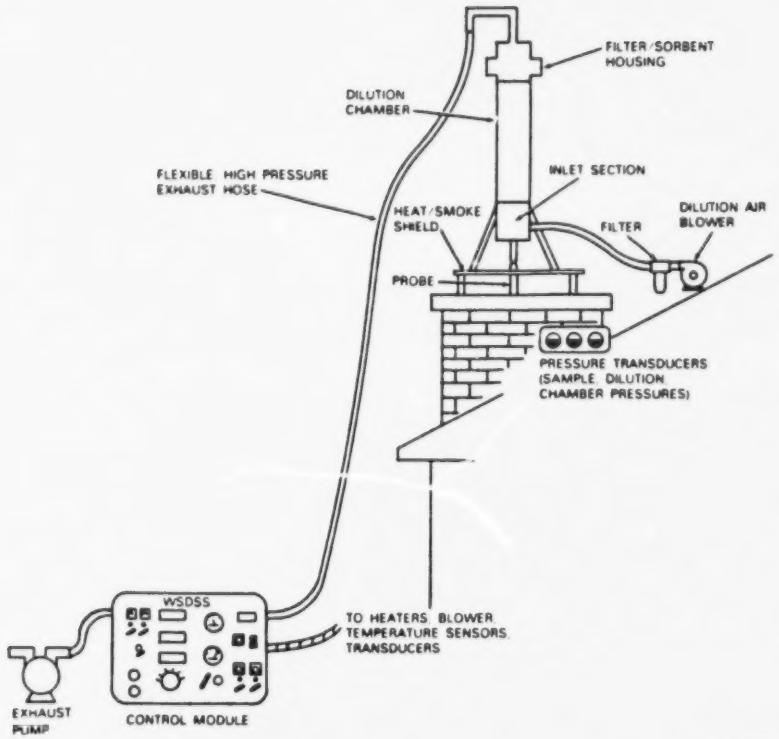

Figure 1. Diagram of the Wood Stove Dilution Sampling System.

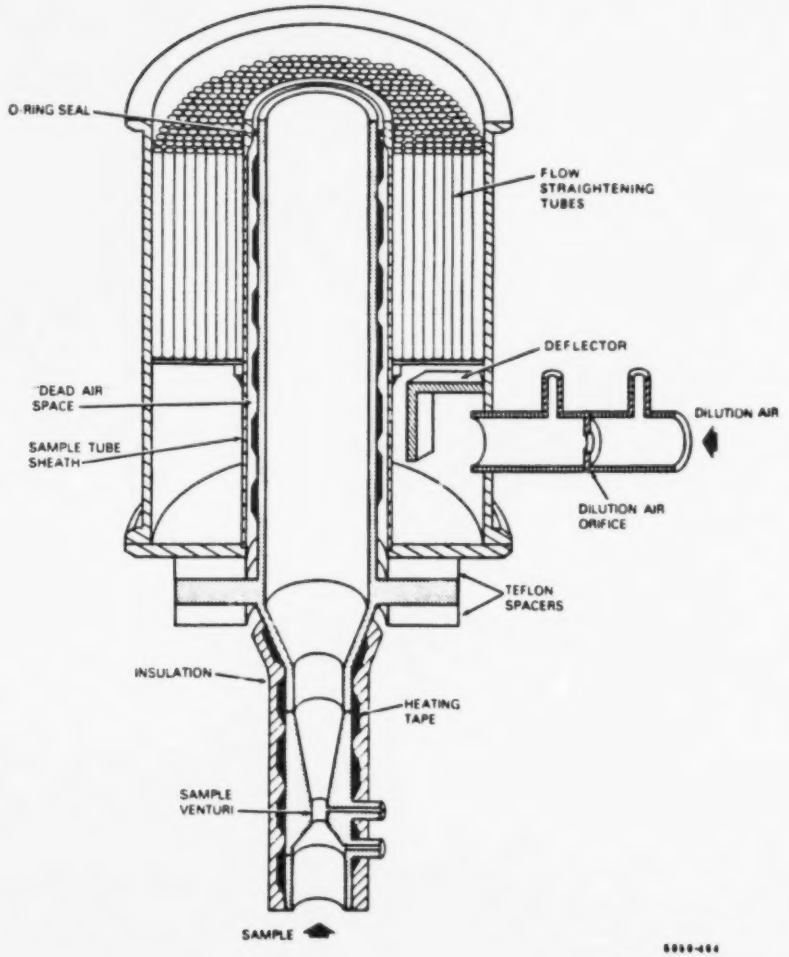

Figure 2. WSDSS sample inlet

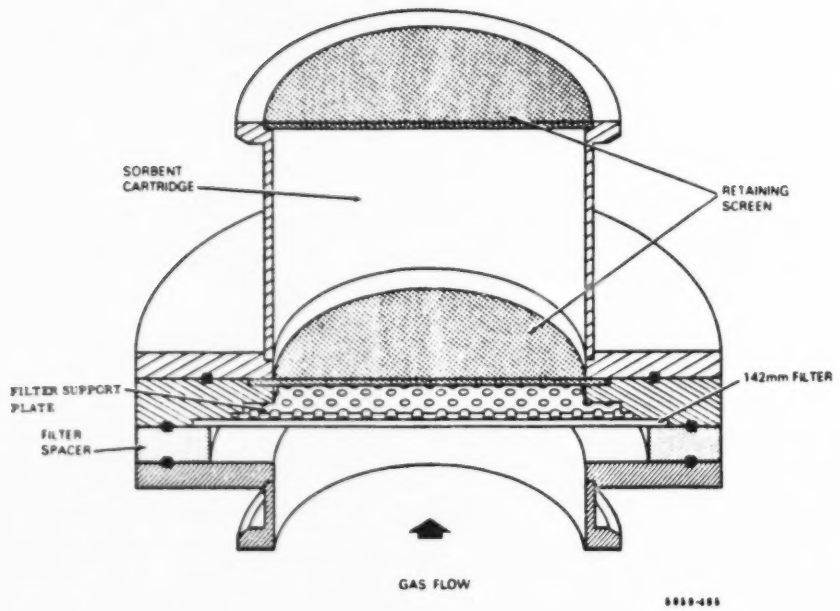

Figure 3. Filter/sorbent housing

cartridge containing approximately 200 g XAD-2 resin. The exhaust gas then exits the housing to the control module and exhaust pump.

Specifications

As with EPA's Stack Dilution Sampling System, the geometric and flow specifications of the WSDSS have been set by several constraints. Ideally, to approximate conditions found in actual plumes, the dilution ratio should be high (approaching 10^3-10^4) and the mixing time should be long (tens of seconds). The dilution ratios presented with the WSDSS represent a compromise dictated by limitations on the size of a portable field instrument to be used on residential chimneys. Geometric and flow specifications are given in Table I.

Table I. Specifications for Wood Stove Dilution Sampling System.

Geometric	
• Active Length of Dilution Chamber	40.625 in. (103.2 cm)
• Diameter of Dilution Chamber	3.87 in. (9.83 cm)
• Diameter of Sample Inlet Tube	0.902 in. (2.29 cm)
• Active Dilution Volume	477.86 in.^{3} (7,831 cm^3)
Flow (Nominal)	
• Sample Flow	~0.25 scfm (7.08 l/min)
• Sample Velocity (93°C)	~15.94 in./sec (40.5 cm/sec)
• Dilution Air Flow	~3.75 scfm (106.2 l/min)
• Dilution Air Velocity (1.7°C)	~10.09 in./sec (25.6 cm/sec)
• Dilution Ratio	~16.1
• Residence Time	4.2 sec
Gas Conditions	
• Sample gas: 60°C < T < 150°C; wood stove emission gas	
• Dilution air: Filtered, ambient air	
Sample Collection	
• Particulate collected on 142 mm filter	
• Organic vapors collected in XAD-2 resin cartridge	

The WSDSS does not precondition the dilution air beyond particulate filtration. The previous system, using a condenser/heater combination, maintained the dilution air at 21.1°C and a moisture content of 0.57% (by volume). This was done in an effort to reproduce the same "standard" dilution air at all sampling locations. The current test objectives of the WSDSS, however, require dilution with air at ambient conditions. Diluting with ambient-condition air will ensure that the plume simulated inside the dilution chamber most nearly represents actual, local plume formation.

Operating Procedures

The dilution ratio, defined as the exhaust flowrate at standard conditions divided by the sample flowrate at standard conditions, is nominally operated at 16:1, with an average exhaust flowrate of 4.0 scfm (0.1133 nm^3/min). As shown in the flow diagram (Figure 4), the sample flowrate, a function of the internal chamber pressure, is monitored by a venturi. The dilution air is monitored by an orifice and adjusted by a blower controlled with a variable transformer. A second orifice in the exhaust line is used to monitor the total flow through the system. Downstream from the exhaust orifice, coarse and fine bleed valves are used to control the total exhaust flow. By achieving a balance between the exhaust pump and the dilution blower, the desired flowrates can easily be maintained throughout the duration of the test. Field experience indicates that this method produces flowrates which can be kept stable for several hours. Control is eventually lost when filter loadings become excessive.

Upon termination of the test, the filter/sorbent housing is removed from the dilution chamber and placed in a cool, dry container for transportation to the onsite laboratory where the filter and sorbent are unloaded and sent to the analytical laboratory for processing. Solvent rinses of the probe and sample inlet (using acetone or dichloromethane) can also be analyzed.

Experimental Studies Using the WSDSS

Although absolute validation of the WSDSS would require extensive simultaneous particulate measurements in the actual source plume, the geometry and dilution process of the WSDSS has been demonstrated successfully by the larger Stack Dilution Sampling System.[1,2,3] However, the reduced scale of the WSDSS dictated that laboratory characterization of the mechanics of mixing be performed to ensure proper performance.

After laboratory verification, the WSDSS was used to obtain samples from the exhausts of several residential wood stoves in the Quail Hollow area of Raleigh, North Carolina.

Laboratory Characterization of the WSDSS

As indicated above, the most critical aspect of this and any other dilution sampling system is the mechanics of mixing of the sample and dilution streams. In order to investigate the dilution process and ensure complete mixing, studies of the velocity and particulate concentration profiles were conducted. These studies were performed using an acrylic and glass prototype of the WSDSS with ten 0.25-in. (6.35 mm) sampling ports spaced approximately logarithmically along the length of the dilution chamber.

The velocity profiles along the length of the dilution chamber were performed with an Alnor 8500 thermal anemometer. These data were obtained by traversing the anemometer probe, in 1-cm increments, across

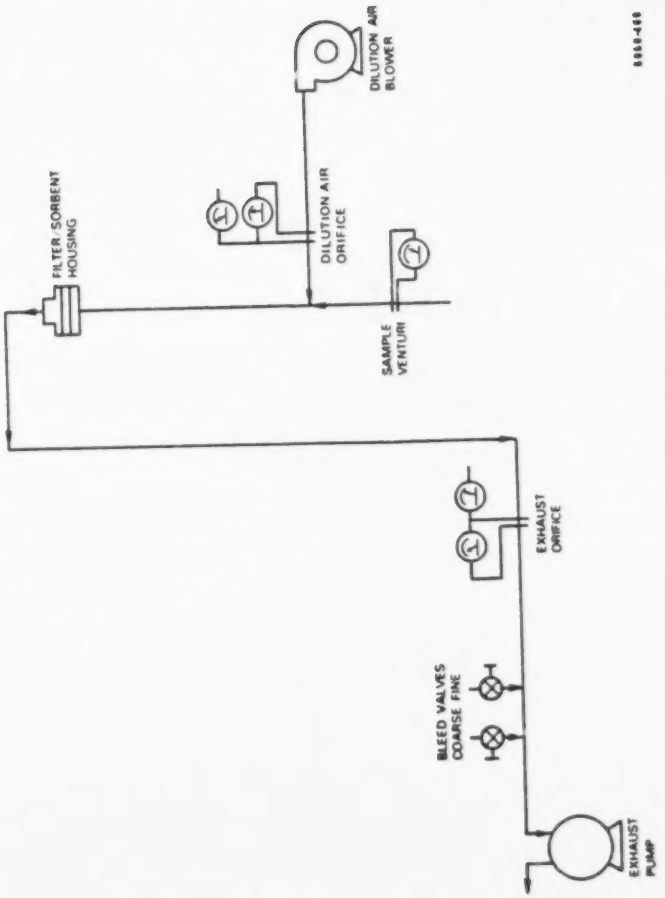

Figure 4. WSDSS flow schematic

the chamber at the various heights indicated in Figure 5A. Throughout the velocity tests, the sample flow was maintained at approximately 0.4 acfm (10 alpm) and the dilution flowrate was about 3.6 acfm (102 alpm). Room temperature air, approximately 72°F (21.7°C), was used for both the sample and dilution flows. As can be seen in Figure 5a, the velocity profile at the port nearest the inlet section clearly shows the varied distribution between the sample and dilution air streams. The profile at this port also indicates that, as expected, the velocity is lowest near the walls of the dilution chamber and in the area directly above the annular sheath between the dilution and sample inlets. The second traverse, 8.9 in. (22.6 cm) above the inlet section, shows a more fully developed profile. The profiles of the remaining two traverses continue this trend. The fully developed profile indicated by the traverse nearest the collection filter, however, shows a slight velocity minimum in the central region of the dilution chamber.

The second diagnostic test on the WSDSS was designed to confirm that the sample and dilution streams are adequately mixed within the length of the dilution chamber. If this does not occur, then the actual dilution seen by the sample will differ from that calculated from the mixing ratio of the two streams. The sample aerosol for this test was drawn directly from laboratory air. A Climet 208 optical particle counter along with a Canberra multichannel analyzer alternately sampled (30 seconds each) diluted aerosol from a probe traversing the WSDSS and direct room (reference) aerosol. The ratio of these concentrations is plotted as the relative concentration. As with the tests profiling the velocity distributions, the sample and dilution flows were maintained at 0.4 acfm (10 alpm) and 3.6 acfm (102 alpm). Figure 5B shows the relative concentration profiles of the WSDSS obtained with both the sample gas and dilution air at room temperature. As expected the lowest traverse shows the sample to be concentrated near the center of the dilution chamber, directly above the sample inlet. At the second traverse the relative concentration shows the sample to still be centered about the core of the chamber, unlike the velocity profile which indicated uniformity at the second level. However, the peak of the curve is less sharp and the sides are beginning to show a more gradual slope. The third traverse still shows a slight peak, indicating incomplete mixing, and is beginning to display a slight bias toward one side of the dilution chamber. The uppermost traverse shows substantial, yet incomplete, mixing for the room aerosol. Also, as was indicated from the previous traverse, a slight skewness exists in the relative concentration profile at the top of the dilution chamber. Previous experience with the Stack Dilution Sampling System indicated that mixing in the dilution chamber is dependent on the temperature of the sample gas. Therefore, a series of traverses was performed across the top of the dilution chamber with various sample gas temperatures: 75°F (24°C), 100°F (38°C), and 200°F (93°C). The results of this series is shown in Figure 6. As can be seen, the distribution of the relative concentration flattens out, indicating essentially complete mixing, at increased sample gas temperatures.

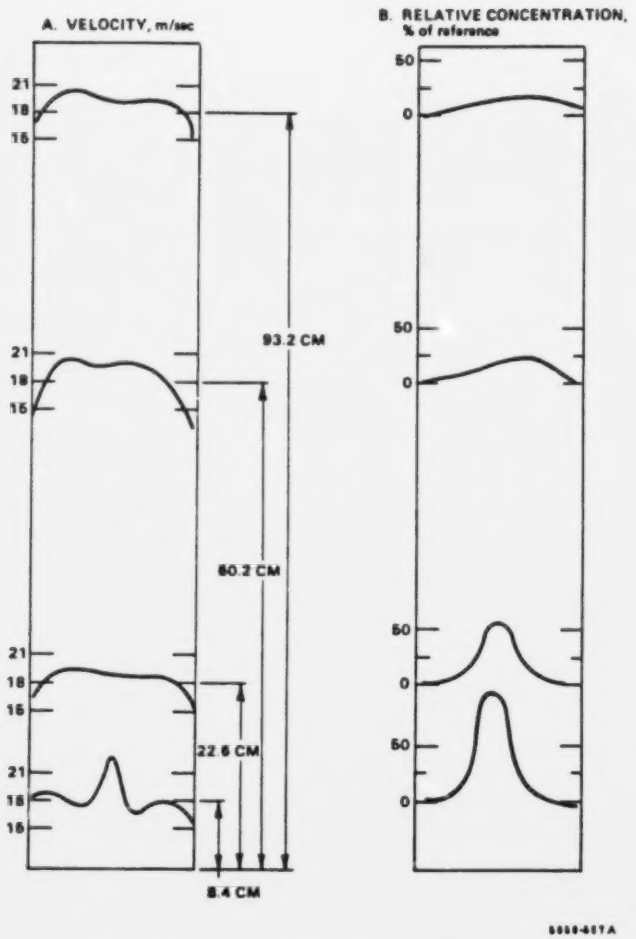

Figure 5. Room temperature velocity and concentration distribution at average dilution and sample flowrate (102 lpm and 11 lpm, respectively).

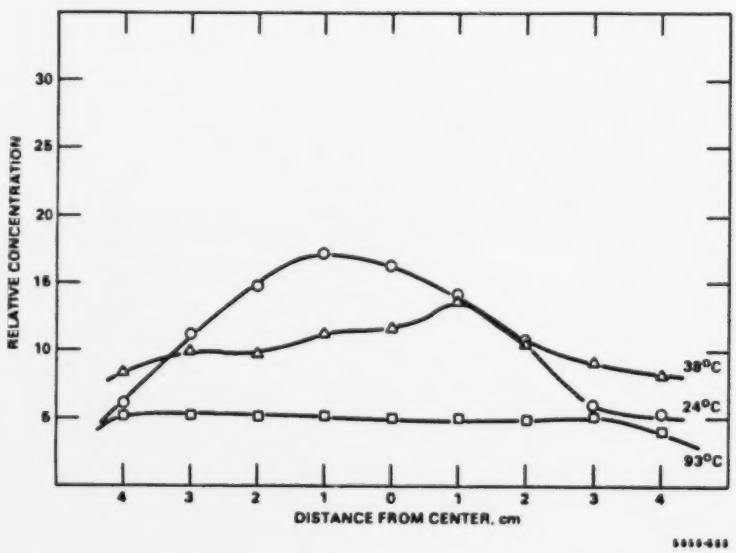

Figure 6. Concentration of diluted test aerosol across top of dilution chamber for 24°C, 38°C, and 93°C sample gas.

Field Measurements Using the WSDSS

Beginning in January 1985, the WSDSS was used for sampling residential wood stove emissions in the Quail Hollow area of Raleigh, North Carolina, as a part of EPA's Integrated Air Cancer Program. Wood stoves were tested at several different residences throughout the test area. Before the Quail Hollow test, a wood stove with a catalytic after burner was tested at one residence near Creedmoor, North Carolina. In an attempt to obtain "typical" condition samples, testing occurred between the hours of 7:00 p.m. and 7:00 a.m., the hours when the residential wood stoves were operated.

The sampling protocol was essentially the same for all the tests. After mounting the dilution system on the chimney and assembling the control module, the operator determined the target flowrates as a function of the desired dilution ratio. The correct sample, dilution, and exhaust flows were obtained by balancing the flows of the exhaust pump and dilution air blower. During most runs it became necessary to exchange filters, due to overloading, before the end of the desired sampling period. When filter blinding occurred, the run was temporarily halted, the loaded filter exchanged for a new filter, and the run sheet was annotated. The exchange was usually accomplished with a down time of 10-15 minutes. For particulate collection, quartz fiber filters were used at the first two test sites and Pallflex Teflon-coated glass fiber filters were used at the remaining locations. As mentioned in the system description, the sorbent cartridge contained approximately 200 g XAD-2 resin for organic vapor absorption. The sorbent unit was sized for 12 hours sample time without breakthrough.

The run parameters and particulate concentration results of this test series are shown in Table II. The results of organic analysis of the XAD-2 resin were unavailable in time to be included here. As can be seen, the dilution ratio averaged 24.7 rather than the nominal dilution ratio of 16.1. The WSDSS was operated at lower sample flowrates in order to obtain a practical filter life before plugging occurred. Table II also shows the mass concentrations which varied from 149.7 to 974.2 mg/dnm^3. The average concentration column contains the composite concentration obtained from one or more filter catches over the duration of 1 day's testing. These concentrations varied from 174.6 to 616.7 mg/dnm^3, with a mean of 374.9 mg/dnm^3. Throughout the testing, the concentration varied not only from site to site and run to run at the same location, but also from filter to filter within the same run. Some of the filter to filter variances may be correlated with changes in operating conditions. These variations are at least as large as site-to-site differences attributable to individual stove variations and differences in operating procedures. It is of some interest that the one stove known to be aided by a catalytic combustor (Run 1-1) indicated the lowest particulate emission rate of the residences tested.

Table II. WSDSS field test results.

	Sample Time (min)	Sample Flowrate (acfm)	Sample Volume ($dsft^3$)	Volume (dnm^3)	Dilution Ratio	Filter Catch (mg)	Concentration (mg/dnm^3) Run	Average
1-1A	150	0.519	49.20	1.393	12.1	275.3	197.6	
1-1B	150	0.460	45.30	1.283	13.3	192.1	149.7	174.6
2-1A	240	0.322	57.60	1.631	16.2	560.2	343.4	343.4
2-2A	360	0.474	123.48[a]	3.497[a]	--	793.9	--	
2-2B	360	0.447	121.32[a]	3.436[a]	--	171.9	--	--
3-1A	330	0.295	70.95	2.009	18.6	415.6	206.9	
3-1B	105	0.225	16.91	0.479	25.0	466.5	974.2	590.6
3-2A	285	0.283	57.29	1.622	20.0	466.5	287.2	
3-2B	415	0.217	63.91	1.810	26.5	8.1[b]	--	287.2
4-1A	70	0.278	13.86	0.393	20.2	303.3	772.7	
4-1B	105	0.283	20.90	0.592	20.2	377.0	636.9	
4-1C	185	0.167	21.46	0.608	34.6	378.4	622.6	
4-1D	320	0.141	31.68	0.897	40.7	476.4	531.0	616.7
4-2A	200	0.282	39.60	1.121	20.2	171.6	153.0	
4-2B	130	0.171	15.73	0.445	32.8	259.1	581.6	
4-2C	360	0.138	35.64	1.009	40.7	160.1	158.6	229.3
5-1A	130	0.277	26.65	0.7557	19.4	426.1	564.6	
5-1B	216	0.263	44.71	1.266	19.2	396.0	312.7	
5-1C	304	0.146	33.74	0.956	35.7	375.0	392.5	402.2
5-2A	255	0.262	52.28	1.481	19.4	449.2	303.4	
5-2B	75	0.261	15.38	0.436	19.4	331.1	760.2	
5-2C	375	0.131	37.89	1.073	39.7	281.8	262.6	355.4

[a]Error in flow measurement--deleted from consideration.
[b]Filter misaligned and ruptured--deleted from consideration.

Conclusions

The prototype Wood Stove Dilution Sampling System developed for these studies has proven itself reliable and easy to operate in both field and laboratory situations. The portability of the system, along with its ruggedness and adaptability, have also become apparent on the various field tests. The system's ability to obtain a wide range of dilution ratios and maintain desired flows will allow future testing on a wide variety of sources with little operator interaction outside of setup and disassembly. Future work concerning the WSDSS will involve analysis of the collected organic vapors and further characterization concerning the effects of varying dilution conditions on the particulate and vapor concentrations measured by the WSDSS.

Acknowledgments

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References

1. Williamson, A. D., J. D. McCain, S. C. Parsons. IP Sampling for Condensible Emissions. Paper 82-61M.3, 75th Annual Meeting, Air Pollution Control Association, New Orleans, LA, 1982.

2. Williamson, A. D. and J. D. McCain, "Condensible Emissions Measurements in the Inhalable Particulate Program". In: Proceedings, Fourth Symposium on the Transfer and Utilization of Particulate Control Technology: Volume III. U. S. Environmental Protection Agency, EPA-600/9-84-025c (NTIS PB85-161917), November 1984, pp. 198-210.

3. Williamson, A. D. and W. B. Smith, "Development of a Sampling Train for Stack Measurement of Inhalable Particulate". In: Proceedings, Third Symposium on the Transfer and Utilization of Particulate Control Technology: Volume IV. U. S. Environmental Protection Agency, EPA-600/9-82-005d (NTIS PB83-149617), July 1982, pp. 297-305.